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Biophysical and biological perspective in biosemiotics

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A B S T R A C T

The cell and its basic constituents are introduced here through a biophysical and information communication theoretic approach in biology and biosemiotics. With this purpose, the requirements of primordial cellular structures, single binding events, and signalling cascades are first mentioned stepwise, in relation to the model of the cellular sensing mechanism. This is followed by the concepts of cross reactions in sensing and pattern recognitions, wherein an information theoretic approach is addressed and the features of multicellularity are discussed along. Multicellularity is introduced as the path that leads to the loss of the direct causal relations. The loss of true causal relation is considered as a form of translation that enables meaning-encoded communication over the informative processes. In this sense, semiosis may not be exclusive. Synthetic biology is exemplified as a form of artificial selection mechanisms for the generation of 'self-reproducing' systems with information coding and processing machineries. These discussions are summarised at the end.

Contents

1. Introduction

Communication of information is a necessary feature in living beings (Kull et al., 2008; Battail, 2013). Advances in technology enables attribution of this feature to machines as well, yet machines are not specified as living beings until now. Similarly, a single sensing event that involves binding of a ligand to a receptor (Bruni, 2007) also involves information communication but is itself a process that takes place in living beings rather than being the sole prerequisite of being a living being, especially considering the fact that such recognition events are currently utilised outside the organisms themselves. Therefore, information communication (Battail, 2009; Barbieri, 2012; Pattee, 2013; Cannizzaro, 2013) should be evaluated as such an essence of life since chemical and

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physical reactions and events are inspected in living beings as a part of their existence (Pattee, 2008; Grandpierre, 2013). It is argued that chemistry and physics has been dealt profoundly in living beings and their informative processes deserve a similar attention. Chemistry and physics of the cells and organisms are tended to be studied for elucidating the functioning mechanisms rather than their role in bringing about the full concept of a living being, other than the approaches in the studies that tackle with the origin of life. Data laden practices in biology were handled similarly by taking their molecular players into account, mainly in terms of the cellular signal transduction, DNA replication, and protein translation events. Self-replicating systems with information coding molecules can be dealt both by the information theory and semiotics, wherein the latter excludes the meaning (*of the message to be transmitted*) for its being irrelevant to the problem of engineering. However, meaning of the message is relevant to the problem of biology and is needed to be integrated to the engineering approach, which is based on information theory. It is suggested here that the type of communication that favours processing the message according to the meaning can be regarded as a feature of the living beings' that resulted in the evolution of living beings from self-replicating systems to interpreters, namely where they stand as living beings, complex organisms. A selection mechanism or a conditional preference for interpreting the meaning (*of the message to be transmitted and processed after being received*) could have acted on the existing self-reproducing systems with information coding molecules and processors. Here, artificial and natural selection mechanisms are offered to be a means of creating biased message transmission services in the cell and the organism. Artificial selection mechanisms are exemplified in the context of synthetic biology and natural selection mechanisms in the context of epigenetics.

Overall, this work is following a bottom-up approach in the sense that it is introducing the basic concepts and attempting to present a unified perspective. It includes the following sections and sub-sections after this introduction, section 1: 2. Basis, 3. Structure and Gradients, 4. Driving Force, 5. Model of the Cellular Sensing Mechanism, 5.1 Specific and Less Specific Single Bindings, Signalling Cascades, 5.2 Special Conditions, 5.2.1 Cross Reactions, 5.2.2 Molecular Binding Patterns, 5.2.3 Multicellularity, 6. Selection Mechanisms and Biosemiotics Processes, and 7. Final Discussion, 8. Summary. The first three sections are presenting the introductory-type concepts of the cell and its basic constituents that are of concern here, namely the requirement of a compartmentalisation for creating, maintenance and control of the changes in gradients. Afterwards, specific and less specific single binding events, signalling cascades are mentioned in relation to the model of the cellular sensing mechanism. Then, two special conditions are stated. Those are the cross reactions, pattern recognitions, and multicellularity wherein the features of multicellularity are broadly discussed as the core of this work. In the end, selection mechanisms are exemplified as the candidate sources for the evolution of 'self-reproducing' systems with information coding and processing machineries. Eventually the presented discussions are summarised after a final discussions section that further elaborates the concerns. The organisation of this work is attempting to follow a scientific (Barbieri, 2009) and holistic (Magnus, 2008) approach with a molecular biophysical perspective (Kull, 2007; Pattee and Kull, 2009; Barbieri, 2011).

2. Basis

Information communication is a prerequisite of life as we understand it (Kull et al., 2008; Battail, 2013). This takes place both within the organism and with the organism and its environment. The organism can be unicellular and multicellular (Hoffmeyer, 2015). Both the eukaryotic and prokaryotic cells are meant here by the term unicellular. Endosymbiosis, which supposedly took role in the generation of eukaryotic cells, is a distinct communication type that requires further special attention. It will not be dealt in this work but to make it clear, the type of communication between the rest of the cell and the plastid or the mitochondria should be regarded as inter-cellular communication. Communication can take place between numerous cells regardless of the organism of interest's being unicellular or multicellular. Therefore, communicating cells' population size is a parameter of importance in case of both the unicellular and multicellular organisms. Hence, there is immense variation due to the size of the communicating population of the cells, considering the size variation of the cell populations. However, types of communications would be different in these two conditions. Another variation source is the environmental specifications that somehow characterises the nature and content of the information and the communication itself.

3. Structure and gradients

Starting from the very beginning, as a primordial form or a developed form, a cell requires inevitably a compartmentalised structure (Ozansoy and Denizhan, 2009). Compartmentalisation is required for circumventing the cell itself and its own other compartmentalised sub-structures. Compartmentalisation is critical because it is required for communicative interaction and compositional stability. Compositional stability is a term which is inherently related to the *homeostasis*. Homeostasis precludes that there is a necessity of maintaining the status in terms of the compositional variations. This maintenance is the driving source of living-being-like dynamic systems. Its importance can be inferred from the fact that most of the energy in a cell is normally spent on this maintenance and the communications related to it. These compositional variations are observed as crowding (Foffi, 2013) and gradients. This concept has similarities with the diffusible gradients that were previously asserted to lead to pattern formation in the organism during development. This was stated to be out of question by Richardson (2009) and also the concern here is not to discuss in deep if the patterns are the outcome of the gradients or not. There exist gradients and there are different forms of gradients that are inherent to the cell. Concentration, potential, temperature, and pressure gradients are among some possible types of gradients (Fig. 1). Gradients are created, maintained, sensed when they change, and are themselves changed to send a signal or as a sign of a signal.

4. Driving force

Random diffusion is the general mode of molecular diffusion in a static environment. When there is compartmentalisation, any molecule that is being accumulated in the body of a cell will end up in disruption of random diffusion of that specific molecule around the cell. This is simply because there will be depletion of the molecule by the cell and the depleted molecule will thus diffuse towards the depleting source since it will be more concentrated at other regions (Fig. 2). This type of directed molecular diffusion is a sort of migration. In Fig. 2, a simplified scheme of such a migration is shown together with a representative molecular binding, as the first step of cellular sensing. The types and features of this sensing are discussed in the next sections. Directed diffusion can be mediated by such sensing events when the molecule of interest cannot pass through the cell membrane directly, which is mostly the case. The concept is also of interest in the disciplines that deal with analysing and designing molecular communication systems